RATIONALE FOR MISSOURI'S PROPOSED NUTRIENT CRITERIA RULE - April 7, 2008

Executive Summary

The United States Environmental Protection Agency (EPA) published *National Strategy for Development of Regional Nutrient Criteria* in 1998 to promote the inclusion of nutrient criteria into state water quality standards. In July 2005 EPA approved the plan for criteria development proposed by the Missouri Department of Natural Resources, and a stakeholders group has been meeting regularly since October 2005.

The proposed rule focuses on reservoirs >10 acres in surface area located outside the Big Rivers Ecoregion. The stakeholders will continue to work towards criteria development for Big River water bodies, auxiliary sites on large reservoirs (>2000 acres), streams, rivers and wetlands.

Development of nutrient criteria is an issue that is complicated by a number of factors that include:

- Nutrients are naturally occurring in aquatic ecosystems and background concentrations can vary considerably.
- Use-impairments are not directly caused by nutrients, but instead are a result of algal growth associated with nutrient enrichment.
- Algae are required for a healthy aquatic ecosystem.
- Missouri's water bodies have multiple uses and the range of algal biomass associated with impairment differs by uses.
- The majority of Missouri's water bodies are man-made reservoirs, built after large-scale land disturbances had occurred to Missouri's landscape.

Most water quality standards are set using a use-impairment approach, which identifies impairment to a designated use (or unacceptable risk of impairment) and relates it to a specific level of pollutant. The scientific sub-committee had difficulty identifying impairment associated with algal biomass for some uses, or when impairment could be identified, relating it to a specific quantity of algal biomass. Another quandary in using a use-impairment approach was accommodating multiple uses such as swimming and fishing. Use-impairment for these two activities occurs at different points along the gradient of water quality. Because of these issues, the scientific sub-committee felt a use-impairment approach to setting nutrient criteria was not practical.

In lieu of a use-impairment approach, the scientific sub-committee has developed a matrix for decision making concerning phosphorus concentrations in Missouri's reservoirs. The matrix was created using three components; 1) a line predicting reservoir phosphorus concentration based on reservoir morphology and watershed characteristics, 2) a line representing the upper quartile of reference conditions, and 3) a line identifying reservoirs with exceptionally low phosphorus concentrations.

The goal was to identify those reservoirs that have excess phosphorus so reductions could be made, which would reduce the risk of algal blooms that can cause use-impairment. The matrix also identifies the reservoirs with the lowest phosphorus levels so they can be protected from nutrient enrichment and prevents decreased water clarity. Nitrogen and algal chlorophyll criteria would be set based on nitrogen-phosphorus and chlorophyll-phosphorus relationships and the phosphorus standards. The proposed approach to setting nutrient criteria is one that the scientific sub-committee agrees is well balanced and would serve the state well.

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Nutrient Criteria Background and Timeline

In 1998 the U.S. Environmental Protection Agency (EPA) published the *National Strategy for Development of Regional Nutrient Criteria* in response to renewed concerns about nutrient enrichment of the nation's surface waters (Kennedy 2001). The impetus for moving forward with criteria development was rooted in the fact that ~50% of surface water impairments reported by states were attributed to excess nutrients and the related biological growth (EPA 2000). EPA set as a goal for states to have nutrient criteria rules in place by 2003 (EPA 1998). The difficultly inherent in developing nutrient criteria rules was punctuated when no states were able to meet the 2003 deadline.

In October 2003, a document entitled *Developing nutrient criteria for Missouri lakes* was presented to Missouri Department of Natural Resources (MDNR). This report, written by University of Missouri (MU) limnologists Dr. M.F. Knowlton and Dr. J.R. Jones, represented a review of water quality in Missouri's lakes and their professional opinion concerning the development of nutrient criteria for the state. In summary, Knowlton and Jones felt there was "too little information on the relationship between nutrients and specific water quality impairments (except for reduced water clarity) with which to formulate numerical criteria for nutrients specific to statutorily protected water uses" (Knowlton and Jones 2003). A starting point, it was noted, might be to set phosphorus criteria to maximize water clarity to the extent achievable for individual lakes. Factors such as lake depth, hydrology and traditional land use within watersheds could be used to predict achievable water clarity (Knowlton and Jones 2003).

In July 2005, MDNR and EPA agreed on a nutrient criteria plan for Missouri that had as a goal the promulgation of rules governing criteria in lakes and reservoirs by the end of 2006 (MDNR 2005). The first Nutrient Criteria Stakeholders meeting was held in October 2005, with meetings occurring on a monthly basis. By December 2006 a number of options had been discussed by the stakeholders for setting criteria for lakes and reservoirs in the state, but none were acceptable to the stakeholders group as a whole. In January 2007 a scientific sub-committee was formed to focus on developing well reasoned and defendable approaches to nutrient criteria. The sub-committee met on a monthly basis and slowly pieced together the current proposed approach. As the approach was developed, reports back to the stakeholders took place. This rationale represents the combined work of both the sub-committee and the stakeholders group in developing a workable plan for Missouri that meets EPA requirements.

The Nutrients and Algae

Phosphorus and nitrogen are the two nutrients listed as causal variables to be addressed by states in the development of criteria (EPA 2000). Aquatic ecologists have long known the importance of these two nutrients in regulating plant growth in lakes, with one or both nutrients often limiting plant biomass (Sakamoto 1966).

Both phosphorus and nitrogen are naturally occurring in the environment, and the nutrients themselves are not a direct danger to the aquatic life within the lake or to humans using the lake for recreation. The nutrients act as fertilizers in lakes, with algal growth being the response variable of concern in Missouri.

Algae are plant-like organisms suspended in the water column or attached to substrate. They are mostly microscopic, though individual cells can form colonies which may be seen as clumps or "surface scums" in the open water or as mats of green growth on the bottom. Algae are an important part of the lake ecosystem, making up the base of the food web which fixes solar energy into usable organic matter for other aquatic life. While algae are important for a healthy lake, excessive algae can negatively impact water quality. Large algal blooms affect aquatic life by causing considerable fluctuations in dissolved oxygen levels within the lake. During the day an algal bloom will give off a large amount of oxygen as a byproduct of photosynthesis, leading to high concentrations of dissolved oxygen. At night the algae and other aquatic life use oxygen through respiration. This respiration along with decomposition of organic matter can reduce dissolved oxygen levels low enough to harm aquatic life (e.g. fish kill). Also, algal blooms can reduce the recreational value of a lake by decreasing water clarity (EPA 2000).

While nutrients and algae are naturally occurring in our lakes, the inherent background level of nutrients found within a water body varies. The natural background level of nutrients is not of concern to EPA, instead the focus of criteria development is excess nutrients associated with human influences in the watersheds.

Nutrient Forms, Algal Estimators, Units of Measure and Methodologies

There are various forms of both phosphorus and nitrogen in natural waters. Some nutrient forms are dissolved while others are bound to inorganic materials or integrated within organic matter. The proposed criteria will focus on what is commonly known as total phosphorus and total nitrogen. Simply put, we are not concerned with the individual forms of the nutrients, but in the total amount of the nutrients inclusive of all forms.

Calculating algal biomass is both time-consuming and costly so algal biomass is often estimated by measuring the photosynthetic pigment chlorophyll. EPA lists chlorophyll as one of the response variables that states should focus on during nutrient criteria development (EPA 2000). This rationale and the proposed rule will use the measure of total chlorophyll as a surrogate for algal biomass.

In this rationale and in the proposed rule all phosphorus, nitrogen and chlorophyll values are presented using the same unit of measure, micrograms per liter (µg/L). Because we are interested in the total amounts of phosphorus and nitrogen, reported values represent the weight of the element of interest and not the weight of a compound (ex. a phosphorus value of 10 □g/L would equate to 10 □g of phosphorus and not 10 □g of PO_4). It should be noted that micrograms per liter is often considered the equivalent to parts per billion (ppb).

The majority of water quality data used in the development of nutrient criteria originated from the MU limnology laboratory, and were produced following Quality Assurance Project Plans (QAPP) approved by MDNR and EPA. Data generated in the future for the purpose of nutrient criteria compliance should be a product of the same methods or methods that can be shown to produce comparable data. The following are the laboratory methods used by MU for analyses of nutrients and chlorophyll:

> Total Phosphorus is measured using the ascorbic acid method (method 4500-P E) after persulfate digestion (method 4500-P B5) as presented in *Standard Methods for the Examination of Water and Wastewater* (APHA 1995).
>
> Total Nitrogen is measured using the Second Derivative Method (Crumpton *et al.* 1992) after persulfate digestion.
>
> Total Chlorophyll is measured fluorometrically after extraction in ethanol (Knowlton 1984, Sartory and Grobbelaar 1986).

Nutrients and algal chlorophyll are highly variable on the temporal scale in Missouri's reservoirs (Knowlton *et al.* 1984, Knowlton and Jones 2006b). Chlorophyll varies the most, with individual reservoir maximum and minimum values differing on average by a factor of 22. By comparison, maximum and minimum phosphorus values differ on average by a factor ~7, while nitrogen varies by an average factor ~4 (Knowlton and Jones 2003). Because of this high variability, sufficient monitoring is required to ensure that calculated mean values for nutrients and chlorophyll are truly representative of reservoir water quality (Knowlton and Jones 2006a, Knowlton and Jones 2006b). Past research on Missouri's reservoirs indicates that appropriate monitoring should include data from at least four summers, with at least four samples collected during each summer (Knowlton and Jones 2006b). This level of monitoring will allow the state to meet EPA's recommendation that "the method of data gathering for compliance should be near as possible to that used to establish the criteria" (EPA 2000).

Because of the natural variability in nutrient and chlorophyll data, geometric averaging has been used in the development of the proposed rule. This technique for defining the central tendency is less influenced by extreme values than simple arithmetic averaging. The science sub-committee recommends the use of geometric mean calculations for all future nutrient criteria efforts.

EPA Approaches to Nutrient Criteria

EPA's *Nutrient Criteria Technical Guidance Manual* lists determination of reference conditions as a cornerstone to nutrient criteria development (EPA 2000). In short, EPA suggests states monitor water quality in the least impacted/most pristine lakes and reservoirs within the state. Nutrient levels in the reference water bodies could be used either as part of the process of criteria development or the final criteria could be set based on reference lake data (EPA 2000). If states use reference data to set criteria, EPA recommends the 75th percentile of the data distribution as the criteria (EPA 2000).

A second approach that uses data distribution to identify criteria is suggested if states do not have a sufficient number of reference lakes and reservoirs. This approach focuses on data from all monitored water bodies within the state. EPA recommends using the 25th percentile of this data distribution as a parallel to the 75th percentile of reference data (EPA 2000).

A third option is for states to use ecoregional data that has been assembled by EPA. This is an option that would allow states with little or no historic monitoring of lakes and reservoirs to be able to generate criteria. The approach is to simply use the 25th percentile of data from the ecoregion distribution. A comparison of phosphorus, nitrogen and chlorophyll criteria based on these three different approaches is shown in Table 1.

These three approaches suffer the same major short-coming; all reservoirs within a region are held to the same criteria without regard to the morphological, hydrological or biological differences among the reservoirs. These "one size fits all" approaches could fail to protect those reservoirs that currently have exceptional water quality (if criteria values are set too high), target some reservoirs for unobtainable nutrient reductions (if criteria are set too low), or a combination of the two problems (if criteria are set at a moderate level).

Table 1. A comparison of potential criteria based on three suggested EPA approaches.

Region	Approach	TP (µg/L)	TN (µg/L)	CHL (µg/L)
Plains	Reference	58	820	22.9
	Population	31	675	11.5
	Ecoregion*	40	660	5.6
Ozark Border	Reference	41	660	19.7
	Population	20	495	5.2
	Ecoregion	30	615	9.1
Ozark Highlands	Reference	26	490	8.2
	Population	9	275	2.3
	Ecoregion	24	500	6.1

*A few reservoirs in the northwest corner of the state would fall into a separate EPA ecoregion. Criteria for these reservoirs would be: phosphorus 55 µg/L, nitrogen 965 µg/L and chlorophyll 18.8 µg/L.

The stated goal of nutrient criteria is to protect the designated uses that are impaired by elevated levels of algal biomass (EPA 2000). One conceivable approach to developing nutrient criteria would be to identify the various impairments to lake uses, tie those impairments to algal biomass, and then correlate the algal biomass to phosphorus and nitrogen concentrations. In theory, lakes and reservoirs meeting nutrient criteria would not have algal biomass that would cause the various use-impairments.

The science sub-committee chose not to pursue this approach for setting nutrient criteria because use-impairments can be difficult to identify and correlating impairments to specific nutrient levels can be impracticable. Uses in which the identification of impairments can be difficult include: resident and migratory wildlife habitat, storm and flood storage attenuation, industrial process and cooling water, and irrigation. For uses where impairments can be identified the impairments do not necessarily relate to measures of algal biomass. In drinking water reservoirs the presence of disagreeable tastes and odors can be considered as an impairment, but not all taste and odors are directly related to algae. Inorganic chemicals such as reduced species of iron, manganese and sulfur can be the source of taste and odor problems, as can organic chemicals associated with bacteria (Knowlton and Jones 2003). Not all algae produce taste and odors, and when taste and odor problems associated with algae do occur, the problems are a factor of algal speciation and not the over-all algal biomass.

Another problem with using the impairment-based approach to developing nutrient criteria is the fact that Missouri's reservoirs support multiple uses. Two of the most common uses are fishing and swimming, which differ greatly in terms of the algal biomass associated with optimal water quality. A reservoir with exceptional water clarity might be considered perfect for swimming, but would lack the algal growth to maximize fish production. On the other hand, the best fishing lakes in Missouri are never crystal clear.

Missouri's Lakes and Reservoirs

Missouri has an extremely diverse population of lakes and reservoirs, with approximately 1800 water bodies >10 acres in surface area. The majority of lakes in Missouri are constructed impoundments (reservoirs), with the natural lakes generally being limited to oxbow lakes and "blew holes" located within river flood plains. The state currently lists 458 water bodies as classified waters.

About a third of the classified waters (141 of 458) are reservoirs that have been monitored sufficiently to allow for adequate description of average phosphorus, nitrogen and algal chlorophyll concentrations. Data from these monitored water bodies were used in the process of developing the proposed criteria. The following is a brief review of the range of both the factors that are important in influencing water quality (Table 2) and the observed long-term water quality (Table 3). The goal of this review is to communicate the diversity of Missouri's water resources.

Missouri's reservoirs span an extremely wide range of morphological conditions (Table 2). This range is somewhat skewed by the fact that along with moderate sized "community" lakes, the data set contains a dozen reservoirs that are over 2000 acres in size. When these large reservoirs are removed from the analyses, we still find a very diverse collection of reservoirs, with surface areas, dam height and volume spanning 6 to 1576 acres, 15 to 139 feet, and 48 to 27,680 acre/feet, respectively.

Watershed size also varies considerably even after the large reservoirs are removed from the data set, with a range of 83 to 174,000 acres. Along with size, watershed land cover differs greatly in Missouri. In the 141 watersheds analyzed, the current amount of forest land cover ranges from 0 to 95% of the watershed, grassland ranges 0 to 78%, crop ranges 0 to 74% and urban ranges from 0 to 96% (Jones *et al.* 2004). While current land cover is not to be used in setting nutrient criteria (EPA, per comm), research has shown that current land cover plays a strong role in determining reservoir water quality (Jones *et al.* 2004, Jones *et al.* 2008).

Table 2. Minimum, maximum and median values for important reservoir morphology and watershed measurements.

	Minimum	Maximum	Median
Surface Area (acres)	6	53,814	103
Dam Height (feet)	15	252	45
Volume (acre/feet)	48	2,700,000	1,675
Watershed Area (acres)	83	>4,000,000	2,516
Residence Time* (months)	0.08	108	10.5

*Residence time is a hydrological calculation that describes the average amount of time it takes for a reservoir's inflow to equal the reservoirs's volume.

Just as reservoir morphology and watershed characteristics vary greatly in Missouri reservoirs, so does water quality. Some of Missouri's reservoirs are categorized as oligotrophic (low plant productivity) and have very low nutrient and chlorophyll concentrations. These reservoirs are best described as clear and blue. On the other end of the spectrum, some of Missouri's reservoirs are hypereutrophic (extremely high plant productivity) and have excess nutrients concentrations and very high chlorophyll values. These reservoirs tend to have very low water clarity, are green in color, and may have "surface scums" of algae.

In monitored reservoirs, long-term geometric mean phosphorus concentrations range from 6 to 170 µg/L (Table 3). Nitrogen spans an order of magnitude among Missouri's reservoirs, with geometric mean values ranging from 200 to 2235 µg/L, while geometric mean chlorophyll values range from 1.1 to 56.7 µg/L.

Table 3. Minimum, maximum and median long-term geometric mean values from 141 monitored reservoirs.

	Minimum	Maximum	Median
Phosphorus (µg/L)	6	170	39
Nitrogen (µg/L)	200	2235	723
Chlorophyll (µg/L)	1.1	56.7	14.2

In order to provide a visual representation of the variability found in Missouri's reservoirs, geometric mean phosphorus concentrations are shown as bar plots (Figure 1 - 3). The reservoirs have been divided according to ecoregion in order to show that even when regional differences are accounted for, there is still substantial variation in water quality. Data from the Plains Region of the state, which consist of northern and western Missouri, is shown in Figure 1. Each horizontal bar represents an individual reservoir in this region, with geometric mean phosphorus scaled along the x-axis. In the Plains Region, reservoirs have phosphorus levels that range from 14 -170 µg/L (Figure 1). In the Ozark Highlands Region (southern Missouri) geometric mean phosphorus ranges from 6 - 59 µg/L (Figure 2), a notably smaller range than measured in the Plains Region. The Ozark Border Region of the state is a transitional zone between the Plains and the Highlands. Phosphorus concentrations in this region range from 12 - 87 µg/L (Figure 3). All three regions display considerable among-system variability, with minimum and maximum phosphorus means differing by a factor of 12, 10 and 7 in the Plains, Highlands, and Border regions, respectively.

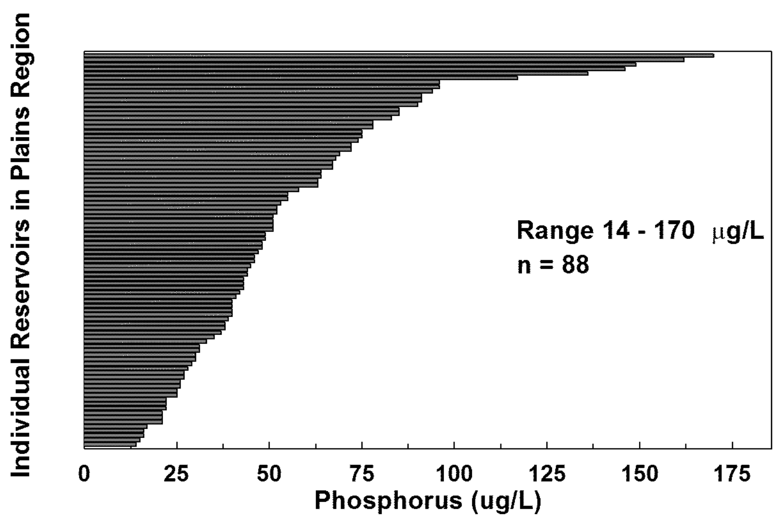


Figure 1. Distribution of geometric mean phosphorus values for monitored reservoirs in the Plains Region.

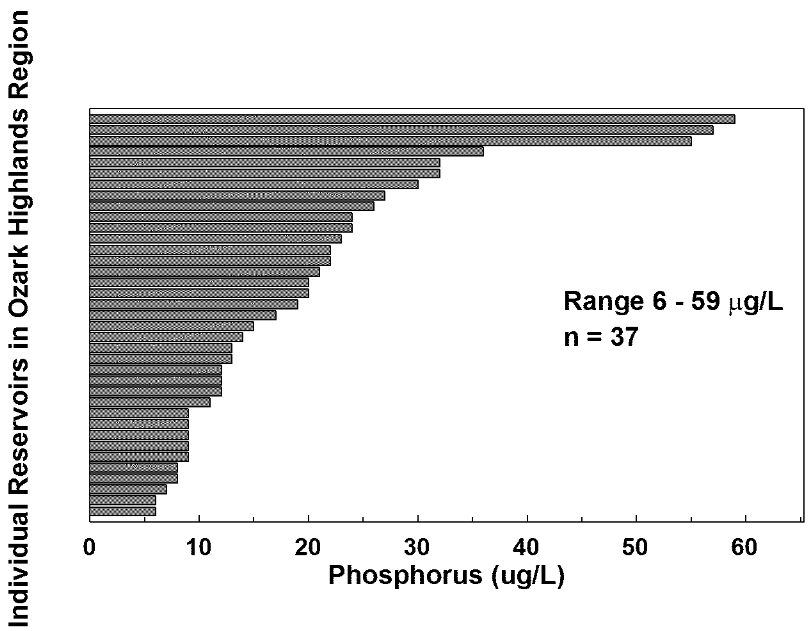


Figure 2. Distribution of geometric mean phosphorus values for monitored reservoirs in the Ozark Highlands Region.

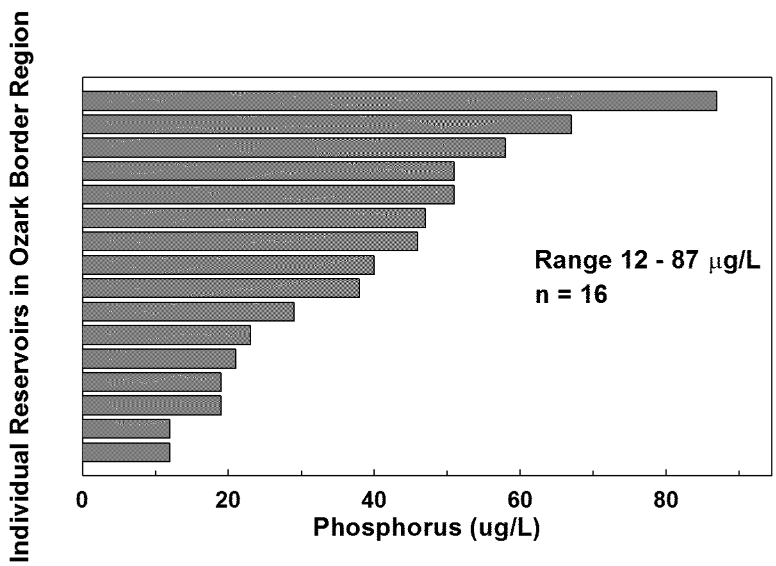


Figure 3. Distribution of geometric mean phosphorus values for monitored reservoirs in the Ozark Border Region.

Relationships between Water Quality Parameters in Missouri's Reservoirs

Missouri has a wealth of water quality data on its reservoirs and numerous scientific articles have been published concerning nutrients and their relationship to algal chlorophyll (Knowlton *et al*. 1984, Jones and Knowlton 1993, Knowlton and Jones 1995, Jones *et al*. 1998, Jones and Knowlton 2005, Knowlton and Jones 2006a, Knowlton and Jones 2006b). Algal chlorophyll shows strong correlations to both phosphorus and nitrogen in Missouri reservoirs (Figures 4 & 5). As nutrient concentrations increase across the range of values found in the state, there is a predictable increase in the amount of algal chlorophyll.

Figure 4. The relationship between phosphorus and chlorophyll in Missouri's reservoirs. Symbols represent geometric mean values from individual reservoirs and the line represents the average relationship between the two parameters. [r^2 = 0.84]

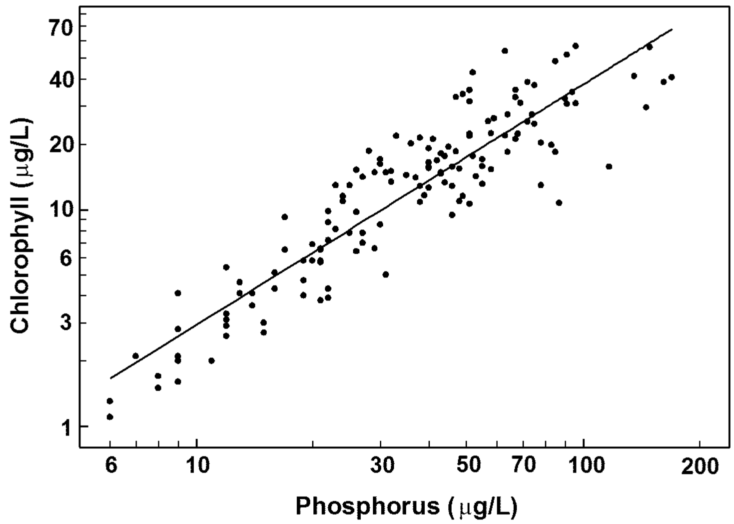
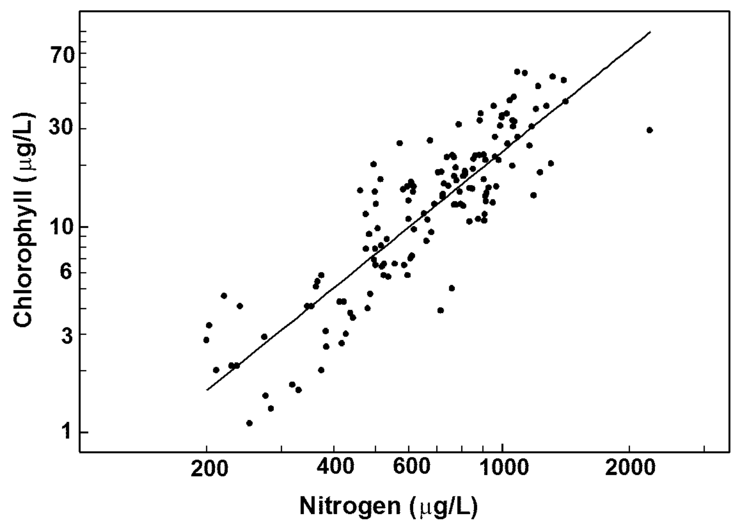


Figure 5. The relationship between nitrogen and chlorophyll in Missouri's reservoirs. Symbols represent geometric mean values from individual reservoirs and the line represents the average relationship between the two parameters. [r^2 = 0.77]



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Chlorophyll correlates to both phosphorus and nitrogen because the two nutrients tend to co-vary strongly in Missouri's reservoirs (Figure 6). Reservoirs with low levels of phosphorus tend to have low concentrations of nitrogen, while reservoirs with high levels of phosphorus have high concentrations of nitrogen. This correlation between phosphorus and nitrogen occurs because reservoir and watershed characteristics (including anthropogenic activities) that are important factors in determining water quality influence both nutrients. Because of this tendency for nutrient concentrations to increase concurrently, algal growth in most Missouri reservoirs is not strongly limited by either nutrient individually, but instead may be considered as being co-limited by both nutrients.

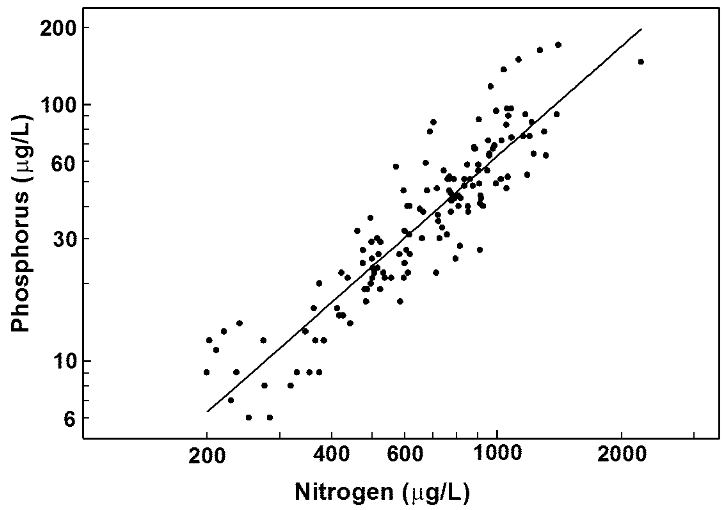


Figure 6. The relationship between nitrogen and phosphorus in Missouri's reservoirs. Symbols represent geometric mean values from individual reservoirs and the line represents the average relationship between the two parameters. [r^2 = 0.82]

Chlorophyll shows a curvilinear relationship to water clarity (measured as Secchi depth). This relationship has two distinct arms where water clarity responds to changes in algal chlorophyll in very different fashion (Figure 7). When chlorophyll levels are low (<6 □g/L) the relationship between transparency and chlorophyll is nearly vertical, with dramatic changes occurring in water clarity associated with relatively small increases or decreases in algal chlorophyll concentrations (Figure 7). When chlorophyll concentrations are >12 □g/L the two parameters display a flat relationship, with water clarity changing very little even when chlorophyll concentrations display substantial shifts. The inflection point, where the relationship changes, occurs when chlorophyll concentrations are between 6 - 12 □g/L.

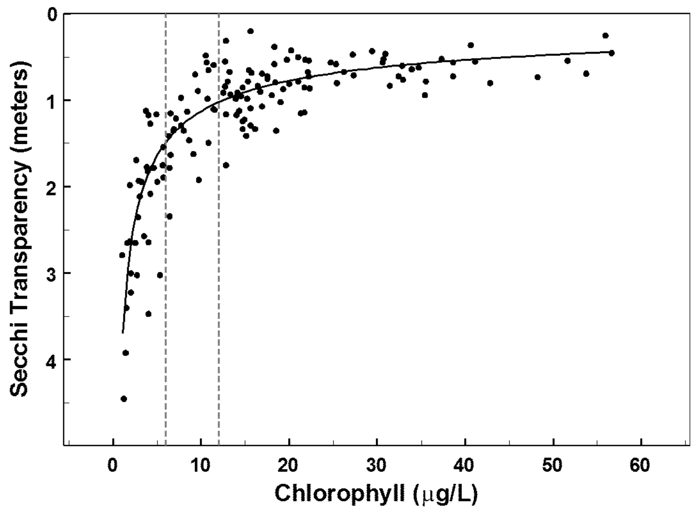


Figure 7. The relationship between algal chlorophyll and Secchi transparency values in Missouri's reservoirs. Symbols represent geometric mean values from individual reservoirs and the solid line represents the average relationship between the two parameters. Vertical dashed lines provide an estimate of the inflection zone. [r^2 = 0.49]

Proposed Nutrient Criteria Approach for Missouri

The science sub-committee proposes an approach that:

1) Separates reservoirs by ecoregion, to reduce the risk of comparing water bodies built in landscapes with different geology, soils and topography.
2) Uses reservoir morphology and hydrology to differentiate reservoirs with varying water quality potential based on factors that were determined when the water bodies were constructed (e.g. volume, watershed area).
3) Determines the range of expected phosphorus concentrations in reservoirs that have nominal human impact within their watershed. This component is a modification to EPA's reference approach.

By using this multi-faceted approach the scientific sub-committee was able to create a matrix that will aid in decision making concerning phosphorus criteria. Actions concerning nitrogen and chlorophyll will be determined using the target phosphorus values.

The proposed rule will be applicable for sites located in deep water near the dam for all reservoirs in the Plains, Ozark Border and Ozark Highlands regions. The proposed rule and this rationale do not address nutrient criteria in Missouri's natural lakes (oxbows and blew holes) or any man-made reservoirs that are located within the

Big Rivers Region (Figure 8). Criteria for these water bodies will be developed at a later time. Criteria for secondary sites on reservoirs with surface areas >2000 acres will also be developed at a later time to address the spatial variability in water quality observed in these large reservoirs (Jones and Novak 1981, Jones and Kaiser 1988, Knowlton and Jones 1995, Obrecht *et al.* 2005).

Regional Divisions

For the purpose of setting nutrient criteria, the scientific sub-committee suggests the state be divided into four ecoregions, which differ in terms of geology, topography, and historic land cover (Figure 8). These factors influence reservoir water quality and should be taken into consideration when setting nutrient criteria. The four suggested ecoregions are:

Plains Region which is located in northern and western Missouri. This region consists of rolling hills that historically had substantial prairie land cover.

Ozark Highlands Region which is located in southern Missouri. This region is described as having steep topography, with historic forest land cover. Soils are often thin with exposed bedrock.

Ozark Border Region is a transitional zone between the plains and highlands. This region has mixed topography and historically had mixed land cover.

Big Rivers Region consists of southeast Missouri's boot heel and floodplains along Missouri and Mississippi rivers. This region is characterized by flat topography and was historically inundated by periodic flooding.

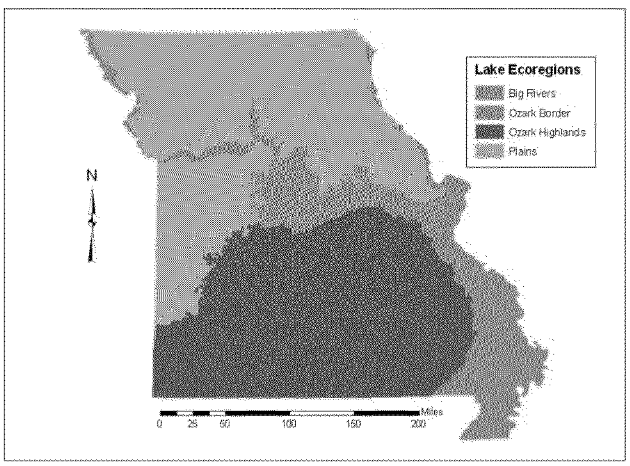


Figure 8. Map of ecoregions.

Influence of Morphology, Hydrology and Historic Land Cover

Reservoir water quality is a function of nutrient inputs from point and nonpoint sources as well as reservoir morphology and hydrology. The relative importance of different reservoir and watershed characteristics in describing cross-system variation in phosphorus concentrations was investigated using multiple regression analysis. Results of this analysis indicate that three factors were significant in predicting phosphorus concentrations in Plains Region reservoirs: 1) proportion of the watershed that was historically prairie, 2) residence time (a measure of hydrology) and 3) dam height. In the Ozark Border and Ozark Highlands regions, only dam height was significant in predicting phosphorus concentrations. Using the results from the analysis, a formula was developed for predicting reservoir phosphorus levels for each region.

Plains: Predicted TP = (% historic prairie/4) + (16/residence time)
+ (570/dam height in feet)
Ozark Border: Predicted TP = (740/dam height in feet) + 15
Ozark Highlands: Predicted TP = (740/dam height in feet) + 5

Historic prairie land cover represents the inherent nutrient levels in the soils in which Plains reservoirs were built. Reservoir nutrient concentrations increase with the portion of the watershed that was historic prairie. Historic prairie land cover was compiled by Jim Harlan (MU geography) based on data collected during the original state survey (circa 1815-1850).

Residence time is the theoretical time it takes water to move through the reservoir and is calculated by dividing the reservoir's volume by the annual amount of inflow. A short residence time equates to high in-reservoir nutrient levels because there is a greater inflow volume (which transport nutrients from the watershed) relative to reservoir volume. Along with less initial dilution of inputs, a short residence time also means less loss of nutrients through sedimentation.

Research has shown the important role that residence time has in influencing nutrient concentrations in Missouri reservoirs (Jones et al 2004, Jones et al 2008). If other factors such as reservoir depth and nonpoint source inputs (represented by % watershed in crop land cover) are held constant, residence time has a predictable influence on nutrient concentrations. This pattern can be seen in Figure 9 where % crop is scaled along the x-axis and predicted phosphorus is scaled on the y-axis. Each line within the figure represents a different residence time (measured in months). For any given level of crop, the predicted phosphorus concentration increases as residence time decreases. This finding suggests that a short residence time can limit a reservoir's potential to reach a low phosphorus concentration, even if a dramatic reduction in nonpoint source pollution is achieved through watershed management.

Dam height is a substitute for reservoir depth, and is an important factor in determining reservoir water quality because shallow reservoirs are more influenced by internal processes such as mixing of the water column. If all other factors were held constant, a decrease in dam height would lead to an increase in nutrient concentrations.

Relationships between predicted phosphorus values and the geometric mean phosphorus values are shown in Figures 10 and 11. Data from the Ozark Highlands and Ozark Border regions have been combined into one graphic because the same factor (dam height) was important in predicting phosphorus in both of these regions (Figure 11). It is worth noting that the relationship for the Plains Region (Figure 10) is stronger than that of the combined Ozark Border and Ozark Highlands. The increased ability to predict phosphorus in the Plains relates to the fact that three independent factors were used to make predictions as opposed to only one factor. Also, the range of phosphorus values in the Plains Region is twice that measured in the other two regions, leading to Figures 10 and 11 being scaled very differently.

Figure 9. The influence of Residence Time (RT) and crop land cover (as % of watershed) on predicted phosphorus levels in Plains Region reservoirs. Note as RT (months) decreases predicted phosphorus increases for all levels of % crop.

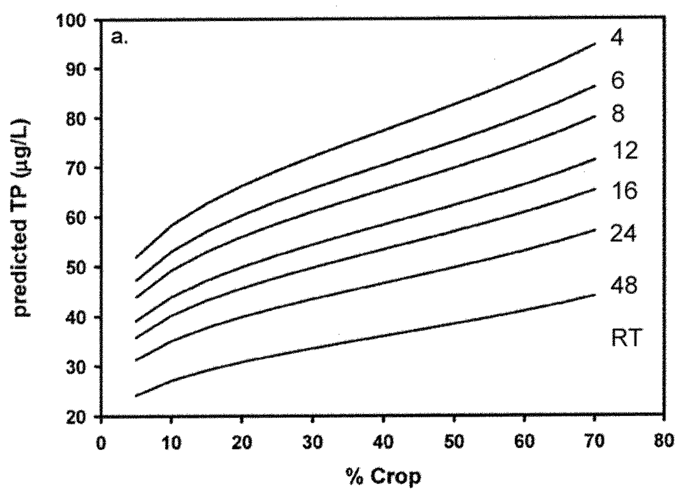
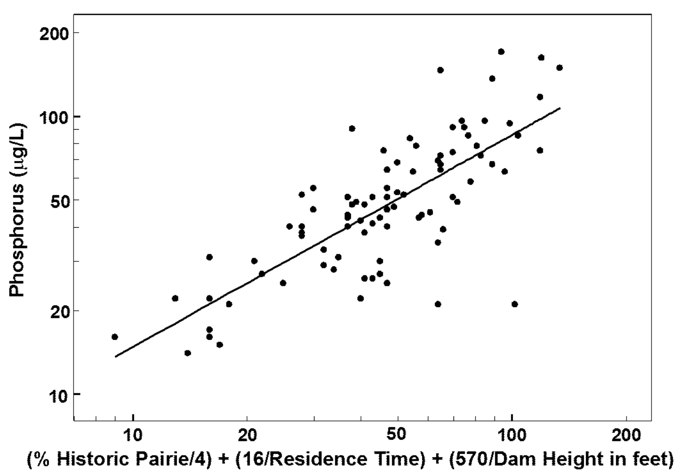


Figure 10. Prediction Line for phosphorus in Plains Region reservoirs. Symbols represent data from individual reservoirs. The line represents the relationship between predicted phosphorus based on reservoir and watershed characteristics (x-axis) and geometric mean phosphorus values (y-axis). [r^2 = 0.58]



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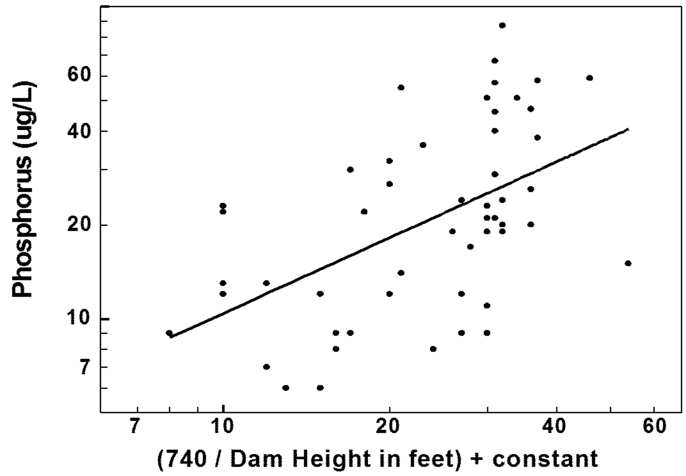

Figure 11. Prediction Line for phosphorus in Ozark Border and Ozark Highlands regions. Symbols represent data from individual reservoirs. The line represents the relationship between predicted phosphorus based on reservoir and dam height (x-axis) and geometric mean phosphorus values (y-axis). The constant values are 15 for the Ozark Border Region and 5 for the Ozark Highlands Region. [r^2 = 0.26]

Reference Reservoirs

The scientific sub-committee decided to use an adaptation of EPA's reference approach to complement the predictive model created using reservoir morphology and hydrology. Reservoirs selected as reference water bodies were not meant to reflect pristine watershed conditions, but instead represent watersheds with relatively low human impact. The goal was to determine the range of in-reservoir phosphorus concentrations that could be expected when watersheds contain nominal human influence. The scientific sub-committee felt that some human influence should be allowable in reference watersheds as most of Missouri's reservoirs were built after 1960 (Knowlton and Jones 2003) and therefore are fairly recent modifications to the landscape. Many of Missouri's classified water bodies are community reservoirs that were built near the towns they serve and by virtue of location, have human impact within the watershed. Given these facts, the scientific sub-committee decided to define reference conditions using the following guidelines, adapted from EPA's guidance document (EPA 2000) and Dodds *et al* (2006):

- Less than 20% of watershed currently in combined urban and crop land cover
- No permitted point sources or permitted CAFOs within the watershed

- At least 50% of current watershed in grass land cover for Plains Region, at least 50% of current watershed in forest land cover for Ozark Highlands Region, and at least 50% of current watershed in combined forest and grass land cover for Ozark Border Region

The number of reservoirs that met these criteria for each ecoregion ranged from 7 to 23 (Table 4). Phosphorus concentrations for reference reservoirs were ordered from lowest to highest and the 10^{th} and 75^{th} percentiles of the range of values were calculated. Horizontal lines were then added to the observed-predicted phosphorus plot to represent the 10^{th} and 75^{th} percentile phosphorus values (Figure 12). The 10^{th} percentile line is referred to as Site Specific Value in the proposed rule. The 75^{th} percentile line is referred to as the Reference Line in the proposed rule and in this rationale. The use of the lines (Predicted, Reference and 10^{th} percentile) and the intersections of the lines creates three main zones in the matrix which will be used to determine the appropriate action when data from individual reservoirs are plotted using predicted and long-term geometric mean phosphorus values (Figure 13). The three main zones can be further broken down into eight sub-zones (Figure 14).

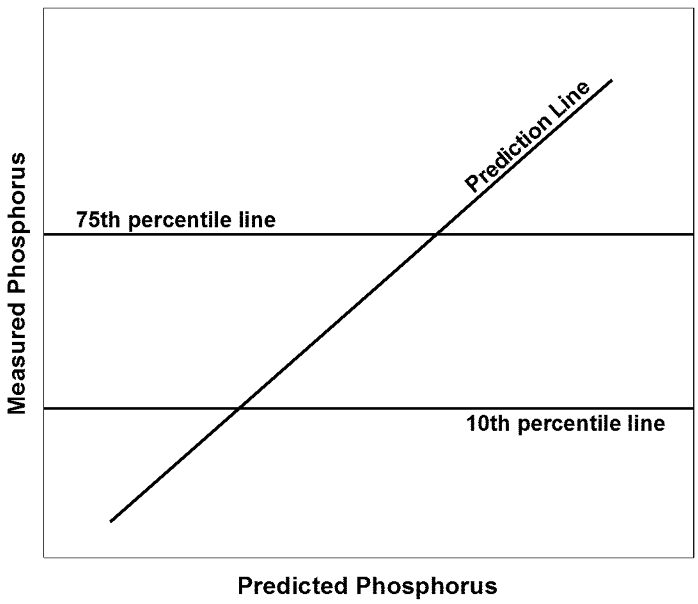

Figure 12. Prediction Line for Plains Region with 10^{th} and 75^{th} percentile lines delineated.

Table 4. The phosphorus ranges, 10th and 75th percentile values for reference reservoirs in each region. Phosphorus values in µg/L.

Region	n	Range	10th %	75th %
Plains	7	14 – 72	20	58
Ozark Border	7	12 – 51	16	41
Ozark Highlands	23	6 - 32	9	26

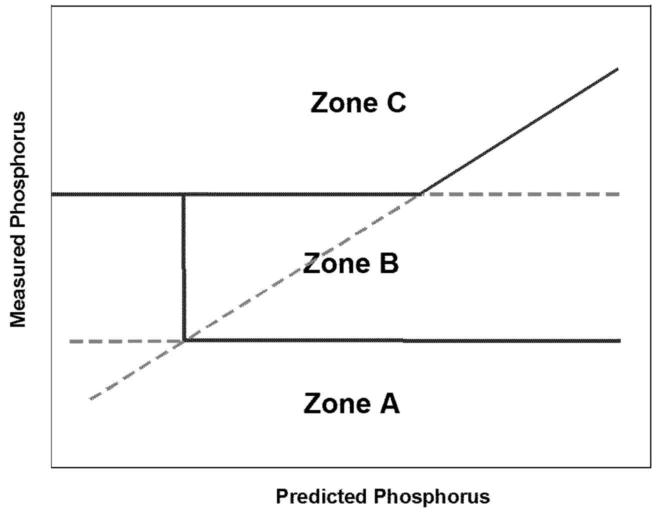

Figure 13. Phosphorus matrix with the three zones of action labeled.

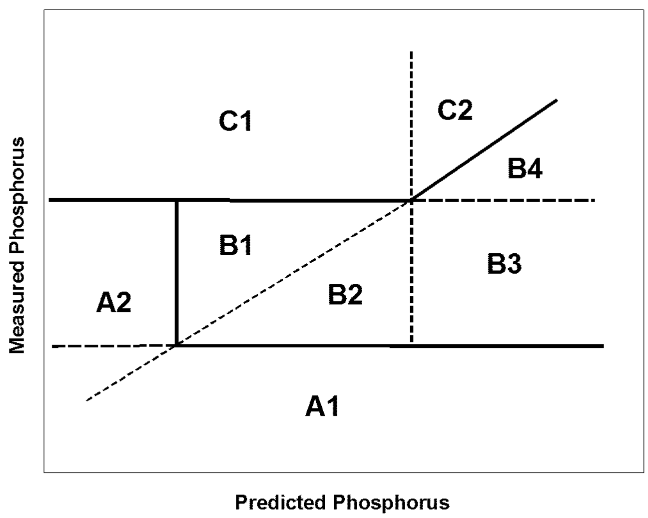

Figure 14. A further breakdown of the matrix into sub-zones.

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Phosphorus Rule

Zone A

Location within matrix – Long-term geometric mean phosphorus concentration is below the 10^{th} Percentile Line (sub-zone A1) or predicted phosphorus value is below the 10^{th} Percentile Line, while long-term geometric mean phosphorus concentration is above the 10^{th} Percentile Line (sub-zone A2) - Figure 15.

Water Quality Standard – Site specific criteria set at current long-term geometric mean phosphorus concentration.

Action Taken - No action taken.

Rationale – Reservoirs located in sub-zone A1 have the lowest nutrient and algal chlorophyll concentrations, along with the highest water clarity within the region. Small increases in nutrient levels would lead to increased algal chlorophyll and decreased water clarity (Figure 7) in these reservoirs. Changes in water clarity could impact recreational uses in these reservoirs. Reservoirs located in sub-zone A2 are predicted to have low phosphorus concentrations, and should be kept from further nutrient enrichment. Phosphorus reduction will not be implemented because these reservoirs have phosphorus concentrations that are within the range found in the reference reservoirs (note: there are only a handful of reservoirs that fall into sub-zone A2, most of which are above the 10^{th} percentile line by only a few micrograms per liter.

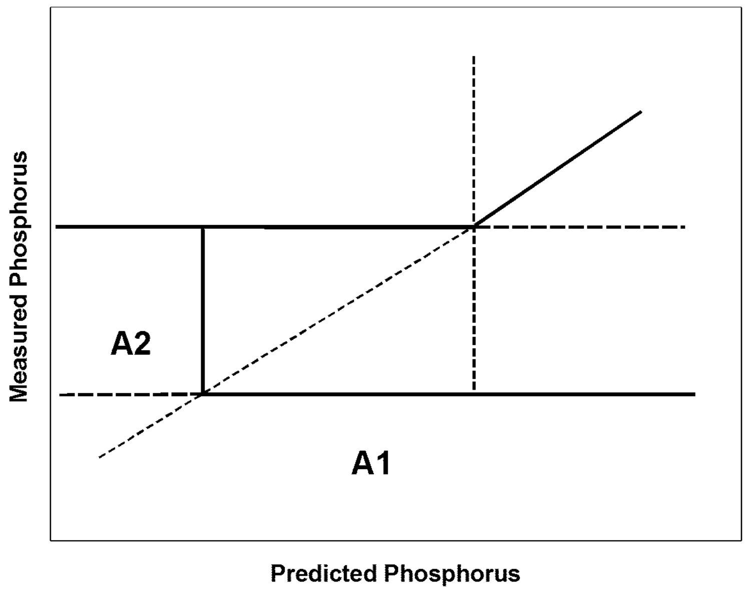

Figure 15. Breakdown of Zone A.

Zone B

Location within matrix – Long-term geometric mean phosphorus concentration and predicted phosphorus concentration are between 10th Percentile Line and Reference Line (sub-zones B1, B2 or B3) or Long-term geometric mean phosphorus is above Reference Line, but below Prediction Line (sub-zone B4) Figure 16.

Water Quality Standard – Phosphorus criteria for reservoirs in sub-zones B1 and B3 will be set at the Reference Value, while reservoirs in sub-zones B2 and B4 will have site-specific criteria set at the reservoir's predicted phosphorus value.

Action Taken - No action taken.

Rationale – Reservoirs located in sub-zones B1, B2 and B3 have long-term geometric mean phosphorus values that are comparable to the majority of regional reference reservoirs, therefore phosphorus levels are deemed acceptable. Reservoirs located in sub-zone B4 are above the Reference Line, but below the Prediction Line indicating less phosphorus than expected given reservoir and watershed characteristics, therefore current values are acceptable.

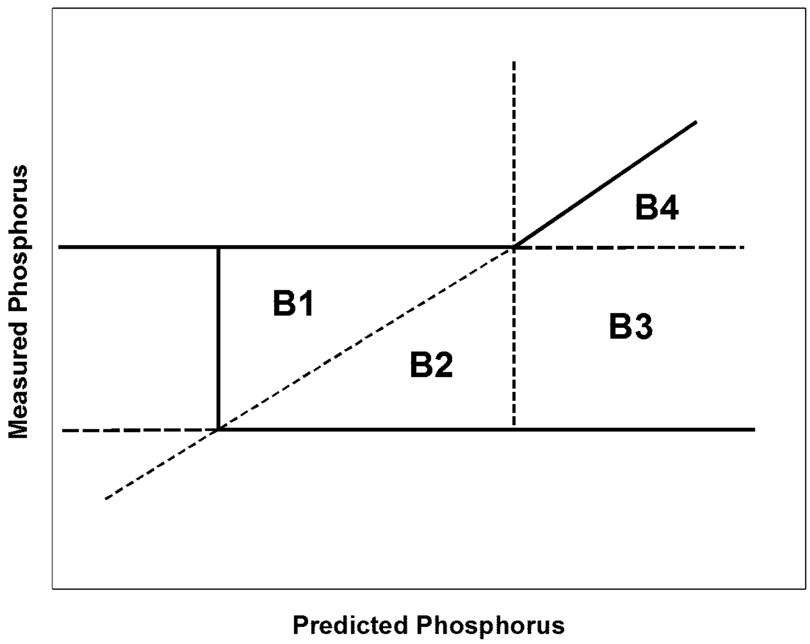

Figure 16. Breakdown of Zone B.

Zone C

Location within matrix – Long-term geometric mean phosphorus value is above the regional Reference Line and Prediction Line (sub-zones C1 and C2) Figure 17.

Water Quality Standard - Reservoirs in sub-zone C1 will have the regional Reference Value as the water quality standard, while reservoirs located in sub-zone C2 will have site specific phosphorus criteria set at the reservoir's predicted value.

Action – Reduce phosphorus concentration to Reference Value (sub-zone C1) or predicted value (sub-zone C2).

Rationale – Reservoirs in Zone C have more phosphorus than predicted and more phosphorus than the majority of reference reservoirs within the region. These reservoirs are at the highest risk for algal blooms that could cause impairments to aquatic life and recreational uses.

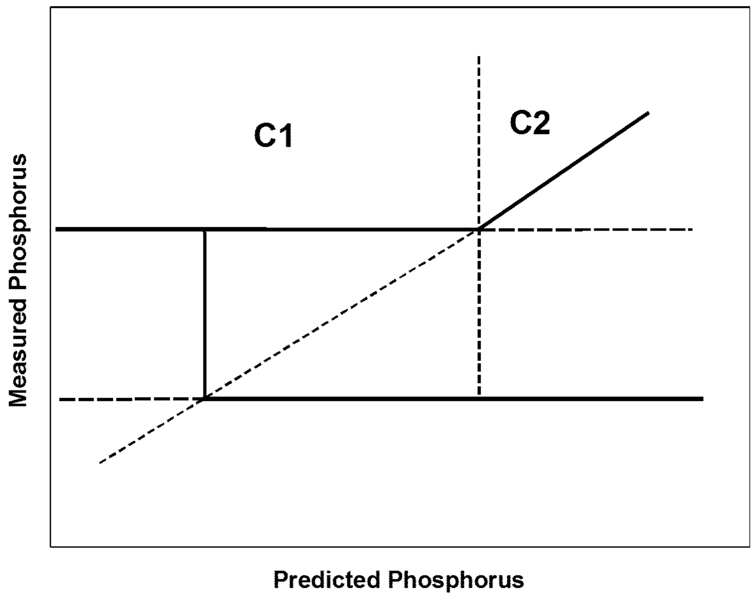

Figure 17. Breakdown of Zone C.

Considerations concerning Nitrogen

While phosphorus is often mentioned as the most important predictor of algal biomass in lakes and reservoirs, aquatic ecologist have long known the importance of nitrogen to algal growth (Naumann 1929, Sakamoto 1966, Elser *et al.* 1990). In Missouri, algal chlorophyll correlates to both phosphorus and nitrogen (Figures 4 & 5) explaining 84% and 77% of the cross-system variability in chlorophyll values respectively (Knowlton and Jones 2003). Because nitrogen is an important causal variable in determining algal chlorophyll, the U.S. Environmental Protection Agency has requested that states address both phosphorus and nitrogen in nutrient criteria plans (EPA 2000).

Research has shown the importance of both phosphorus and nitrogen in promoting algal growth. Work by McCauley *et al.* (1989) indicated that the chlorophyll growth per unit phosphorus increased as the ratio of nitrogen to phosphorus (N:P) increased. That is, nitrogen had a positive influence on algal chlorophyll even when the N:P ratio was high enough to suggest that nitrogen was not limiting algal growth (McCauley *et al.* 1989). In another study, a review of data from 133 lakes indicated that chlorophyll showed the strongest relationship to both phosphorus and nitrogen when the N:P ratios were between 23:1 and 28:1 (Prairie *et al.* 1989).

These findings deviate somewhat from the theory that N:P ratios can be used to identify which nutrient limits algal growth. Sakamoto (1966) was the first to suggest the use of N:P ratio as a gauge, citing an N:P ratio of <10:1 would indicate nitrogen limitation of algal growth, while an N:P ratio >17:1 would be indicative to phosphorus limitation. Other scientists followed Sakamoto with different suggested cut-points (Dillion and Rigler 1974, Downing and McCauley 1992, Levine and Schindler 1992), which underlines the fact that these cut-points are inexact.

A situation where N:P ratios are not successful as a predictor of the limiting nutrient is in lakes and reservoirs that have low nutrient levels (Downing and McCauley 1992). These water bodies may be, by default, co-limited by both nutrients because concentrations are so low.

If N:P ratios can be used to predicted nitrogen limitation, then in theory the ratios could also be used to predict the dominance of nitrogen fixing blue-green algae in lakes. Lakes with low N:P ratios would be perfect environments for algae that have the ability to fix atmospheric nitrogen because these species would have a competitive advantage over species that cannot fix atmospheric nitrogen. Blue-green algae are considered to be the least desirable algae because they can form “surface scums” that reduce aesthetics, they are poor food for other aquatic life, some species can cause taste and odors, and some species produce toxins (EPA 2000). Results from whole-lake experiments in Canada support the theory of blue-green algae dominance in lakes with low N:P ratios (Schindler 1977), as does a review of published data (Smith 1983). Other researchers have suggested that additional factors are important in regulating blue-green algae dominance, and some lakes with low N:P ratios do not suffer from blue-green algal dominance (Knowlton and Jones 1996).

One reason for the discrepancy in the use of N:P ratio as a predictor of nutrient limitation or blue-green algae dominance is the fact that algal populations can be quite diverse. During summer 2000, MU sampled 60 reservoirs from across the state for algal identification. On average, each monitored reservoir had 28 species of algae, with a range of 18 - 40 species (unpublished data).

Research has shown that the optimal N:P ratio varies among algal species, with reported lows near 4:1 and highs near 28:1 (Smith 1982). While 4:1 and 28:1 probably represent the extreme ends of the continuum, it is obvious that diverse algal requirements coupled with high species diversity interferes with the use of N:P ratios as predictors of nutrient limitation or blue-green algal dominance.

<u>Nitrogen Rule</u>

Zone A

Water Quality Standard - Reservoirs located in Zone A of the matrix (Figure 15) will have site-specific nitrogen criteria that are set at the current long-term geometric mean nitrogen value.

Action - No action taken.

Rationale - Reservoirs located in Zone A have the lowest nutrient and algal chlorophyll concentrations, along with the highest water clarity within the region. Small increases in nutrient levels would lead to increased algal chlorophyll and decreased in water clarity (Figure 7) in these reservoirs. Changes in water clarity could impact recreational uses in these reservoirs. Site-specific nitrogen criteria set at current long-term values will offer a level of protection from nutrient enrichment.

Nitrogen reductions will not take place even if N:P ratios are above 20:1 because the use of N:P ratio to predict the limiting nutrient is not applicable at these low nutrient levels. It is also worth noting that most low-nutrient reservoirs in Missouri have forested watersheds, and runoff from these watersheds is expected to have a relatively high N:P ratio (Downing and McCauley 1992).

Zone B

Water Quality Standard - Reservoirs located in Zone B of the matrix (Figure 16) shall have nitrogen criteria set at either 20 times the reference phosphorus value (sub-zones B1 and B3) or 20 times the predicted phosphorus value (sub-zones B2 and B4).

Action - Nitrogen reduction if a reservoir's current long-term geometric mean nitrogen value is greater than 20 times the reference phosphorus value (sub-zones B1 and B3) or 20 times the predicted phosphorus value (sub-zone B2 and B4). If geometric mean nitrogen value is less than 20 times the appropriate phosphorus value (reference or predicted) then no action taken.

Rationale - Reducing nitrogen concentrations to achieve an N:P ratio of 20:1 will move reservoirs below the optimal range of N:P ratios identified by Prairie *et al.* (1989) and should result in lower algal chlorophyll levels. Maintaining N:P ratios at 20:1 will reduce the risk of pushing reservoirs into nitrogen limitation and reduce the risk of creating environments that favor blue-green algal growth. Target nitrogen values are based on the reference and predicted phosphorus values because reservoirs in Zone B of the matrix have these values as water quality standards. The scientific sub-committee felt that setting nitrogen target values to existing geometric mean phosphorus values would be inappropriate given the potential for these values to fluctuate in the future.

Zone C

Water Quality Standard - Reservoirs located in Zone C of the matrix (Figure 17) shall have nitrogen criteria set at either 20 times the reference phosphorus value (sub-zone C1) or 20 times the predicted phosphorus value (sub-zone C2).

Action – Reduce nitrogen if a reservoir's current long-term geometric mean nitrogen value is greater than 20 times the reference phosphorus value (sub-zone C1) or 20 times the predicted phosphorus value (sub-zone C2). If geometric mean nitrogen value is less than 20 times the appropriate phosphorus value (reference or predicted) then no action will be taken.

Rationale - Reservoirs located in Zone C of the matrix are targeted for phosphorus reductions to either the reference or prediction value, therefore these values will be used to calculate the nitrogen target values. Reducing nitrogen to a 20:1 N:P ratio should aid in the reduction of algal chlorophyll in these reservoirs. This is especially true for those reservoirs where phosphorus reductions will be accomplished by implementing best management practices (BMPs). The BMPs could, along with reducing phosphorus, also reduce the erosional runoff from the watershed into the reservoir. Reductions of inorganic suspended solids (from erosional runoff) would create an improved light environment within the reservoir which in turn could promote algal growth. It is possible that reductions of only phosphorus (and the accompanying reduction in ISS) would lead to higher algal chlorophyll levels even though phosphorus concentrations have been decreased. Reductions in nitrogen levels accompanying the reduction in phosphorus should aid in achieving the overall goal of lower algal chlorophyll levels.

<u>Considerations concerning Chlorophyll</u>

Algae are an important component in a healthy aquatic ecosystem, providing both dissolved oxygen and energy to the rest of the aquatic food web. Numerous studies have shown that fish productivity is positively correlated with moderate to high levels of algal biomass. A study of mid-west reservoirs indicated that sport-fish yield is maximized when chlorophyll levels are ~20 - 50 □g/L (Knowlton and Jones 2003). This finding is supported by research at Auburn University which indicates that chlorophyll concentrations of 40 - 60 □g/L correlates to optimal sport-fish production (Maceina 2001).

It is also known that fisheries are not at their healthiest in systems that have excessive algae. An Iowa study showed that while total fish catch per unit effort increased positively with chlorophyll levels, there was a shift from game fish production to rough fish production such as carp (Egertson and Downing 2004). The Iowa study also found that increasing chlorophyll had a negative effect on some game fish species such as bluegill and black crappie. Another problem associated with excessive algal growth in terms of fishery health is the potential for fish kills associated with widely oscillating dissolved oxygen levels (EPA 2000).

We know that reservoirs need algae in order to have healthy fisheries, that fish production may be optimized at a moderate to high level of algal biomass, and that excess algae can have a negative impact on the fishery. What we do not know is the exact point when the positive relation between aquatic life and algal biomass becomes a negative relation. One reason this tipping point is difficult to define is because various studies relating the health of the fishery to chlorophyll use different methods of measuring fish health. Studies have looked at total fish biomass, sport fish biomass, fish growth/productivity, and catch per unit effort. The use of various ways of measuring the health of the fishery prevents easy comparisons among studies. A second factor to consider is that not all fish species have the same optimal water quality. Schupp and Wilson (1993) suggests that optimal phosphorus levels for lake trout, walleye, black crappie and white crappie are 10, 25, 70 and >100 □g/L, respectively. A final factor is the fact that all of Missouri's reservoirs differ in terms of morphology, fish community composition, management, and fishing pressure. Given all of the variables, it is easy to see how a single "tipping point" is impossible to identify.

In Missouri's reservoirs there is a relationship between mean chlorophyll concentrations and maximum measured chlorophyll values (Figure 18). The slope of the relationship approaches 4:1, indicating that for each 1 □g/L increase in mean chlorophyll there is approximately a 4 □g/L increase in maximum chlorophyll (Knowlton and Jones 2003). A reservoir with a mean chlorophyll value of 20 □g/L could be expected to have a maximum value of around 80 □g/L, while increasing the mean value to 30 □g/L would lead to a maximum of around 120 □g/L.

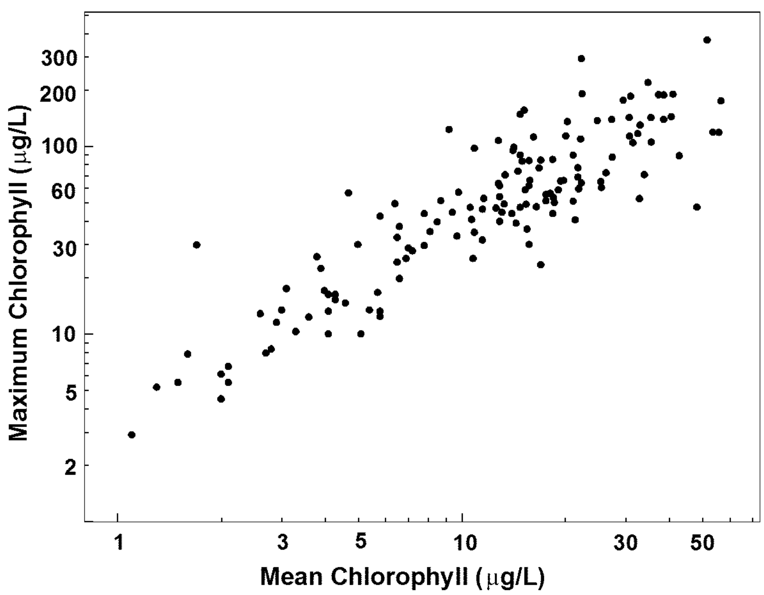

Figure 18. The relationship between geometric mean chlorophyll and maximum chlorophyll values in Missouri reservoirs. Symbols represent data from individual reservoirs and the line represents the average relationship between the two parameters. [r^2 = 0.78]

There is also a trend for the frequency of high chlorophyll measurements to increase with mean chlorophyll (Figure 19). About 4% of individual chlorophyll values were >75 □g/L in reservoirs that average between 20 and 30 □g/L chlorophyll. As mean chlorophyll increases so does the proportion of high values, with reservoirs that average between 30 - 40 □g/L chlorophyll and 40 - 50 □g/L chlorophyll having ~10% and 20% of individual measurements >75 □g/L, respectively (Figure 19).

It is obvious that the risk of high chlorophyll concentrations, which are indicative of algal blooms, increases in both extremity and frequency as mean chlorophyll conditions increase. While we do not know definitively at which point the relation between algal biomass and fish production switches from being positive to negative, we can assume that some of the maximum values that have been measured in Missouri's reservoirs are extreme enough to pose a risk to aquatic life.

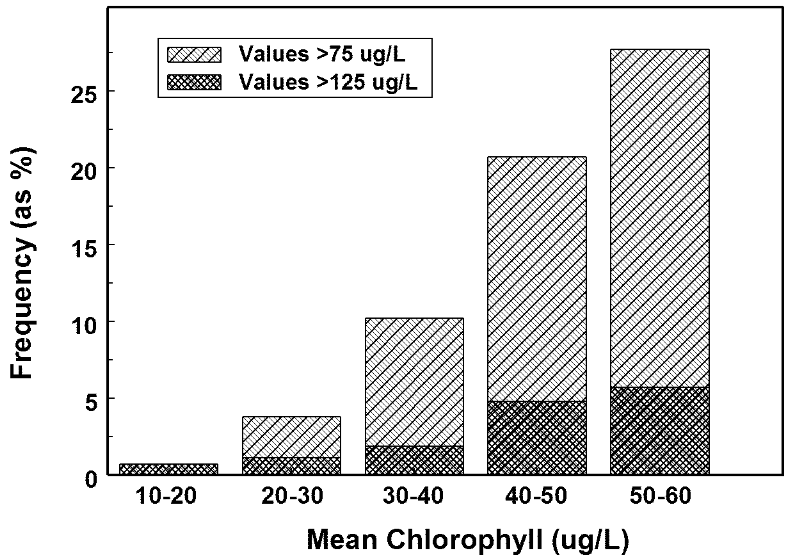

Figure 19. Frequency of high chlorophyll values for reservoirs grouped by geometric mean chlorophyll concentration.

In EPA's guidance document biological community structure is listed as one of the response variables that states can consider when developing nutrient criteria (EPA 2000). This response variable underlines EPA's goal of protecting the biological integrity of lakes and eliminating (or reversing) the loss of aquatic species due to nutrient enrichment. Because reservoirs are man-made systems, they do not have natural biological assemblages. Without natural assemblages to establish a standard, there is no way to gauge biological integrity.

The issue of biological integrity is further complicated by the fact that some Missouri reservoirs were built specifically to provide fishing opportunities for particular species of fish. Other reservoirs were built for different uses, but are highly managed to maintain the fishery. Because these reservoirs are highly managed, the biota maintained within them may not reflect "natural conditions' or "balanced communities."

These reasons, along with the scarcity of research relating algal biomass to aquatic life other than fish in Missouri's reservoirs, have led the scientific sub-committee to focus on fish when considering aquatic life in the development of nutrient criteria.

Chlorophyll Rule

Regional chlorophyll - phosphorus ratio (CHL:P) factors were calculated to aid in the identification of reservoirs that have higher chlorophyll values than expected given phosphorus concentrations. These factors were calculated by taking the average CHL:P ratio for reservoirs that currently meet phosphorus criteria (Zones A and B) within each region and adding one standard deviation (calculated from the same data). The regional CHL:P factors are set at 0.44 for Plains Region reservoirs and 0.42 for both Ozark Border Region and Ozark Highland Region reservoirs.

Zone A

Water Quality Standard - Reservoirs located in Zone A of the matrix (Figure 15) will have site-specific chlorophyll criteria that are set at the current long-term geometric mean chlorophyll value.

Action - No action taken.

Rationale - Reservoirs located in Zone A of the matrix are set at site-specific criteria to offer protection from loss of water clarity that would accompany increased algal chlorophyll (figure 7). Because these reservoirs have low levels of nutrients, they will not be targeted for further nutrient reductions even if geometric mean chlorophyll values are greater than the regional CHL:P factor multiplied by the geometric mean phosphorus.

Zone B

Water Quality Standard - Reservoirs located in Zone B of the matrix (Figure 16) will have chlorophyll criteria set at either the regional CHL:P factor multiplied by the reference phosphorus value (sub-zones B1 and B3) or the regional CHL:P factor multiplied by the predicted phosphorus value (sub-zones B2 and B4).

Action - Reservoirs that have geometric mean chlorophyll values greater than either the regional CHL:P factor multiplied by the reference phosphorus value (sub-zones B1 and B3) or the regional CHL:P factor multiplied by the predicted phosphorus value (sub-zones B2 and B4) will be listed because of excess algal chlorophyll. If geometric mean chlorophyll value is less than the regional CHL:P factor multiplied by appropriate phosphorus value (reference or predicted) then no action taken.

Rationale - Reservoirs that have higher than normal CHL:P ratios will have, by definition, higher algal chlorophyll levels than expected given nutrient concentrations.

Because of increased algal efficiency these reservoirs are more at risk of having extreme chlorophyll values than other reservoirs with similar nutrient concentrations. Target chlorophyll values will be calculated using reference phosphorus or predicted phosphorus values (depending on location in matrix) because reservoirs in Zone B of the matrix have these values as water quality standards. The scientific sub-committee felt that setting chlorophyll target values to existing geometric mean phosphorus values would be inappropriate given the potential for these values to fluctuate in the future.

Zone C

Water Quality Standard - Reservoirs located in Zone C of the matrix (Figure 17) shall have chlorophyll criteria set at either the regional CHL:P factor multiplied by the reference phosphorus value (sub-zone C1) or the regional CHL:P factor multiplied by the predicted phosphorus value (sub-zone C2).

Action - Reservoirs with current long-term geometric mean chlorophyll values greater than the regional CHL:P factor multiplied by the reference phosphorus value (sub-zone C1) or the regional CHL:P factor multiplied by the predicted phosphorus value (sub-zone C2) will be listed because of excess algal chlorophyll. If geometric mean chlorophyll value is less than the regional CHL:P factor multiplied by the appropriate phosphorus value (reference or predicted) then no action taken.

Rationale - Reservoirs located in Zone C are targeted for phosphorus reductions. If phosphorus concentrations are successfully brought down to target levels, but chlorophyll concentrations remain high; there would still be a risk of algal blooms that can impact aquatic life and recreational use.

<u>Summary of how Proposed Rule would affect Monitored Reservoirs</u>

Approximately 15% of the monitored reservoirs in Missouri are in Zone A of the phosphorus criteria matrix. These reservoirs have low phosphorus concentrations and will be protected from future nutrient enrichment. Most monitored reservoirs (60%) are in Zone B, meaning that they are currently in compliance with proposed phosphorus criteria. The remaining 25% of Missouri's reservoirs have phosphorus concentrations that exceed both their predicted value and the regional reference value, and thus would be targeted for phosphorus reductions.

Nitrogen concentrations in the majority of Missouri's monitored reservoirs meet the proposed criteria (84%), while the remaining 16% of reservoirs do not. Note that some of the reservoirs that exceed criteria do so by a small amount and further evaluation may determine that nitrogen reductions are not necessary.

Currently, 62% of monitored reservoirs meet chlorophyll criteria and would not be listed as having excess algal chlorophyll. About 5% of reservoirs have chlorophyll concentrations that exceed criteria, while their nutrient concentrations meet proposed criteria. These reservoirs would be listed as having excess algal chlorophyll. The remaining 33% of monitored reservoirs exceed phosphorus and/or nitrogen standards and would be targeted for nutrient reductions. Because changes in chlorophyll levels can be expected with reductions in nutrients, it is impossible to determine if these reservoirs will meet or exceed chlorophyll standards until they have met nutrient criteria.

Reservoirs located in Zone A of the matrix not only have the lowest phosphorus values within a region, but also tend to have the lowest chlorophyll concentrations (Figures 20 - 22). This is to be expected given the strong relationship between these two parameters (Figure 4). Maintaining phosphorus in Zone A reservoirs at current levels will keep chlorophyll concentrations from increasing. In contrast, reservoirs located in Zone C of the matrix have both the highest phosphorus and chlorophyll concentrations. Phosphorus reductions in Zone C reservoirs would predictably result in lower chlorophyll values.

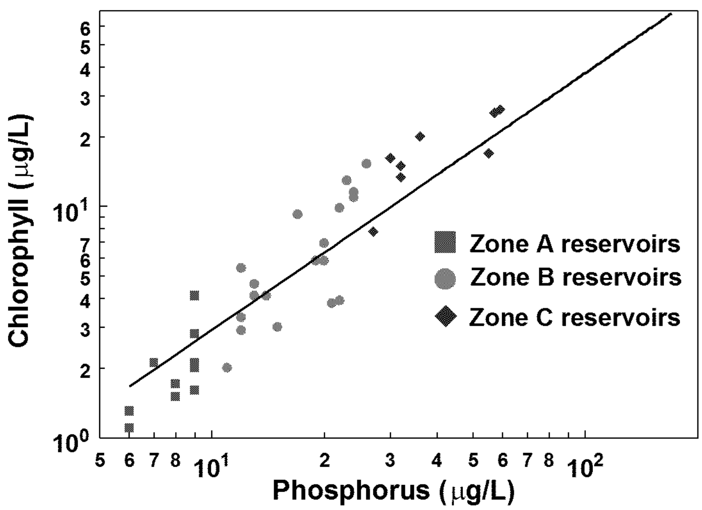

Figure 20. The statewide chlorophyll-phosphorus relationship (line) with reservoirs from the Plains region (symbols) plotted according to location in phosphorus matrix.

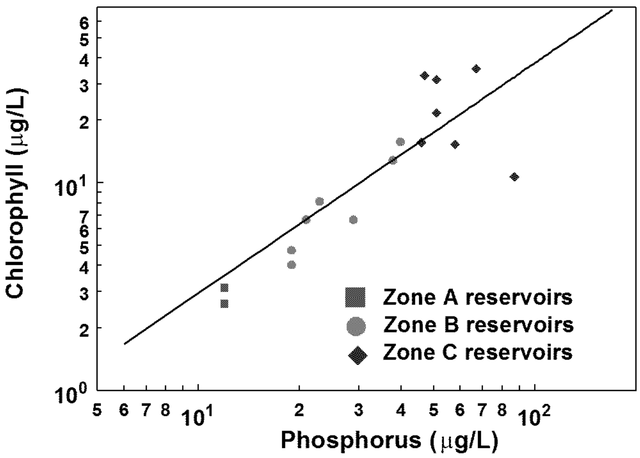

Figure 21. The statewide chlorophyll-phosphorus relationship (line) with reservoirs from the Ozark Border region (symbols) plotted according to location in phosphorus matrix.

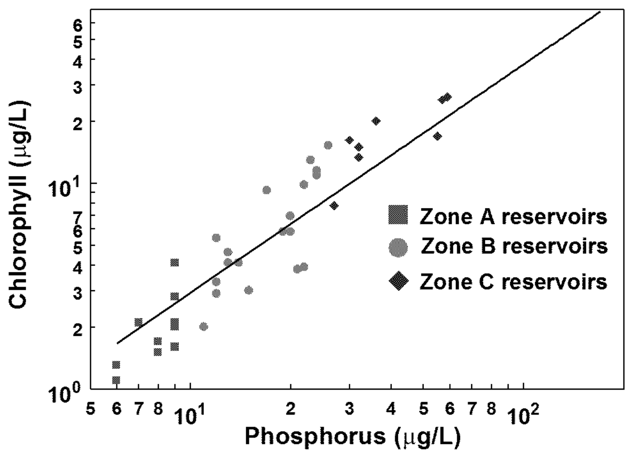

Figure 22. The statewide chlorophyll-phosphorus relationship (line) with reservoirs from the Ozark Highlands region (symbols) plotted according to location in phosphorus matrix.

A better way to evaluate how decisions based on the phosphorus matrix will affect observed water quality in Missouri reservoirs is to look at the Secchi transparency-chlorophyll relationship (Figures 23 – 25). In all three regions we find that reservoirs located in Zone A of the phosphorus matrix are situated on the vertical portion of the Secchi transparency-chlorophyll relationship. Setting nutrient criteria at current levels in Zone A reservoirs will allow these water bodies to maintain exceptional water clarity. Small increases in phosphorus and nitrogen in these reservoirs would lead to a predictable decrease in water clarity. For most of these reservoirs the decrease in clarity would be obvious to the public and judged as a reduction in water quality. Reduced clarity would impair full-body recreation in Zone A reservoirs as some of the public would decide not to participate in full-body recreation due to the loss of water clarity. Zone C reservoirs are generally those with the highest chlorophyll concentrations within each region. Reductions in phosphorus should decrease chlorophyll levels. In reservoirs located on the far right side of the relationship this reduction in mean chlorophyll would be accompanied by a reduced risk in extreme chlorophyll levels associated with algal blooms (Figure 18). For some reservoirs the decrease in phosphorus and subsequent reduction in algal chlorophyll will result in a shift towards the inflection zone of the Secchi transparency-chlorophyll relationship, which will translate to clearer water which would be desirable for full body recreation uses.

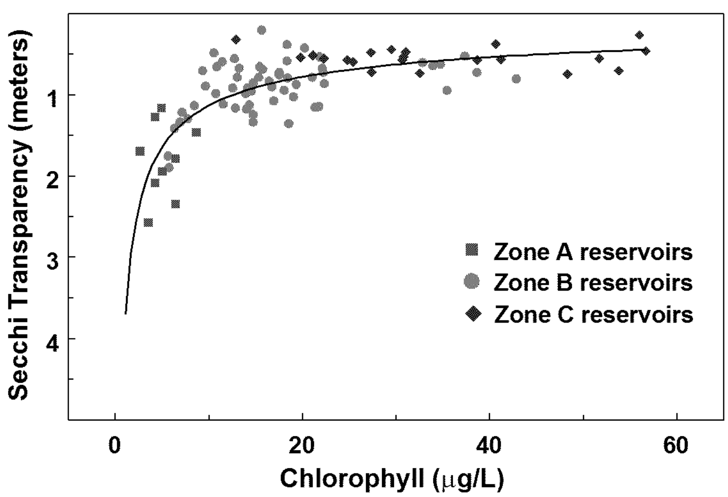

Figure 23. The statewide Secchi transparency-Chlorophyll relationship (line) with reservoirs from the Plains regions (symbols) plotted according to location in the phosphorus matrix.

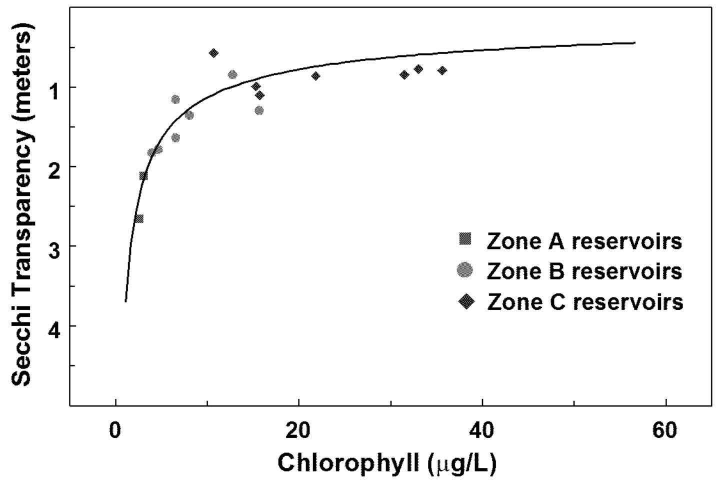

Figure 24. The statewide Secchi transparency-Chlorophyll relationship (line) with reservoirs from the Ozark Border regions (symbols) plotted according to location in the phosphorus matrix.

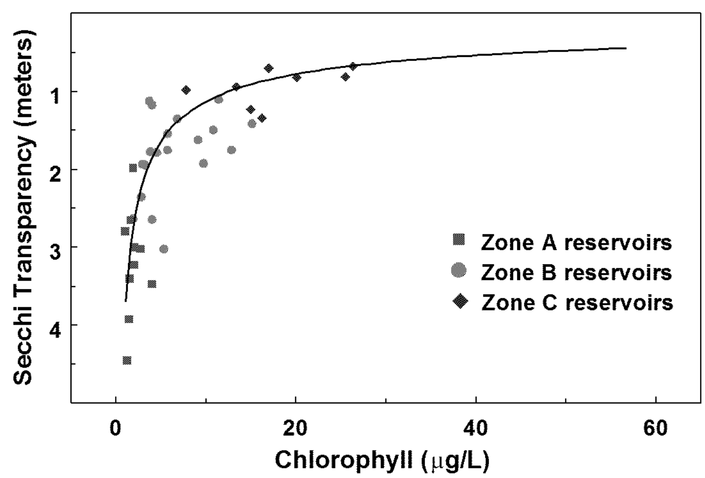

Figure 25. The statewide Secchi transparency-Chlorophyll relationship (line) with reservoirs from the Ozark Highlands regions (symbols) plotted according to location in the phosphorus matrix.

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